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CONCEPTUAL DESIGN FOR A CONTINUOUSLY ADJUSTABLE COLLIMATOR FOR FAST NEUTRON RADIATION THERAPY *†

Miguel Awschalom & Ivan Rosenberg

INTRODUCTION

In all European countries and the U.S.A. where fast neutron clinical trials are being undertaken, the shaping of the neutron beam is done with fixed removable collimators made of a variety of materials such as pressed wood, polyethylene concrete, or water expanded polyester (WEP).

Continuously adjustable collimators have long been in use in photon radiation therapy. This has been possible because photons used in radiation therapy are rather easily absorbed in lead collimators with typical thicknesses of 10 cm or less. On the other hand, neutron collimators, which are customarily made of hydrogenous materials, are rather long (60 to 90 cm). The use of high density materials has been generally shunned to avoid inducing long-lived radioactivity.

In this paper, the conceptual design is presented of a compact continuously adjustable neutron collimator which could be incorporated into an isocentric gantry. The advantages of this design over interchangeable fixed aperture collimators are several:

(1) continuously adjustable neutron field sizes;

(2) reduction in the time needed to set up different fields;

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(3) elimination of special requirements for the storage of radioactive collimators;

(4) elimination of the need for new collimators when treatment plans require sizes not in stock;

(5) elimination of dose to personnel due to collimator removal and reinsertion;

(6) drastic reduction in dose to personnel during patient set-up;

(7) possibility of remote beam dimensioning for dynamic treatment.

DESCRIPTION OF THE COLLIMATOR

Figure 1 shows schematically a collimator cross-section through one median plane. The main components of the system are:

(a) the source, surrounded by

(b) a primary steel collimator, followed by

(c) a space for field light, mirror, and transmission ionization chambers, followed by

(d) the adjustable "collimator", followed by

(e) a spacer, between the adjustable collimator and

(f) the adjustable "trimmer".

Ideally, for the best geometrical penumbra, all the movable beam shaping material should be as close as possible to the patient within the specified collimator-isocenter clearance requirements. However, there are some advantages in separating the system into two sections ("collimator" and "trimmer");

(i) a large part, if not most of the induced radioactivation, would be located farthest from the personnel, in the "collimator", and

(ii) there is a reduction in the total mass of expensive high-density material required for the collimator blades.

To keep the collimating system short, the adjustable "collimator" and the "trimmer" blades should be made of tungsten (in practice sintered tungsten may be used). The motion of the blades could be achieved by means of mechanical linkages and/or computer-controlled motors to permit the edges of the plates to always satisfy the conditions of figure 2, when the system is "open".

When the collimating system is "closed", all the blades of the "collimator" and the "trimmer" would touch each other. Thus, the system would shield the outside from its own, and the target's, remanent radioactivity. This could be programmed to happen whenever personnel enter the room, thereby reducing their radiation exposure during set-ups.

It is obvious that other alternatives exist, such as the "collimator" blades made partly of tungsten and partly of steel and the "trimmer" of tungsten. In all cases the total absorption should remain about the same at the 99.5% level.

COLLIMATOR CHARACTERISTICS

The physical parameters of this conceptual design were derived for a p(66MeV)Be(49 MeV) neutron beam, using the attenuation data obtained by Awschalom et al[1] and the following conditions:

(i) source-axis distance (SAD) = 150 cm

(ii) diameter of neutron source (proton beam on target) = 1 cm

(iii) clearance between isocenter and end of collimating system = 50 cm

(iv) maximum field size at isocenter = 30 x 30 cm^2, as defined by rays from the center of the target to the furthest edges of the "trimmer". This corresponds approximately to the 50% decrement lines.

(v) dose transmission through adjustable blades of the collimating system = 0.5%

This last condition requires a total thickness of about 23 cm of tungsten or about 35 cm of steel[1]. As part of the fixed shielding, the primary collimator is assumed to provide about 15 cm of steel, with the appropriate aperture and taper for the maximum 30 x 30 cm^2 field. However, there are inevitable voids adjacent to the movable blades, deep enough to contain the latter when the largest field is required. The spacer between the two adjustable sections should thus be filled with low and high density neutron shielding material distributed so as to give an additional 20-25 cm equivalent steel thickness along any forward ray. This spacer should also have the appropriate aperture and taper to satisfy condition (iv) above. The movable high density blades should be designed to have about 1 cm overlap with this aperture on all sides when the adjustable "collimator" and "trimmer" are completely closed. These conditions should ensure adequate shielding for all field sizes in the forward direction (0.2 to 0.3 radians from the central axis).

To investigate the effects of the splitting of the collimating system into two sections, several "collimator"-"trimmer" configurations were studied.

Again, ideally, the best beam definition would be obtained with a solid tungsten collimator 23 cm thick, at the "trimmer" position, if this could be achieved in a practical manner. This would be the shortest possible system and would produce the sharpest penumbra. It is equivalent to the fixed interchangeable collimator system, and can be taken as the "ideal case". This system has been designated as model #1.

All practical systems must have interleaving sets of blades for the two orthogonal field dimensions, so that, if the total attenuation needed for each edge is 23 cm of tungsten, the total bulk occupied by the system will be twice as much, or 46 cm thick.

Four more models were thus analyzed, having the following distribution of tungsten between the "collimator" and the "trimmer":

Model #	1	2	3	4	5	6
"collimator"linear density, cm of W	0	0	7.7	11.5	15.3	23
"trimmer" linear density, cm of W	23	23	15.3	11.5	7.7	0
"Tungsten"* mass (ρ = 17g cm^{-3}) kg	154	250	216	192	158	116

*a sintered material having $\rho = 0.90\rho_{tungsten}$ is assumed

Model #6 would put all the adjustable system in the "collimator", for minimum mass of tungsten, but it would have an unacceptably large penumbra, and was not analyzed further.

PENUMBRA CHARACTERISTICS

Figure 2 shows the definition of the nominal field width W_0, and of the parameter δ, the distance into the penumbra measured from the geometrical field edge.

For the calculations of penumbra characteristics in air, it was assumed that:

(i) the proton beam was 1 x 1 cm^2,

(ii) the target had zero thickness, and

(iii) all neutrons were emitted by two lines perpendicular to the plane of the drawing (S_1 and S_2) located 2.5 mm to each side of the median plane.

Then, neutron beams from S_1 and S_2 to D are given weights of 0.5 each and attenuated appropriately as they pass different thicknesses of tungsten(1). As these calculations were made for a relatively small field size, no material was traversed in the "primary collimator" or in the "spacer".

Figure 3 shows details of the penumbra calculated in this manner for a 10 x 10 cm^2 beam. Most of the significant differences are expected to be far less noticeable in a phantom or patient, where the scatter from the medium is very important in determining the beam penumbra at depth. Also, the transmission is expected to be somewhat larger since narrow beam attenuation data are not strictly appropriate for this type of calculation. Finally, scatter from the "collimator", "spacer", and "trimmer" has been ignored.

ENGINEERING CONSIDERATIONS

The mounting and motion of the plates deserve careful consideration. As Figure 2 shows, when the system is"open", the blades are supposed to align themselves with a plane passing through the "edges" of the source. When the system is "closed" all the blade edges should be aligned with the appropriate median planes. These requirements are achievable in a straight forward manner in an environment accustomed to the use of microcomputers for control. Another serious consideration is the need for good fitting and control of blade positions since all angles will be 0.1 radians or less. Each set of "trimmer" blades would weigh around 50 to 75 kg, and the positioning forces will reverse themselves as the gantry rotates from one horizontal position to the opposite one.

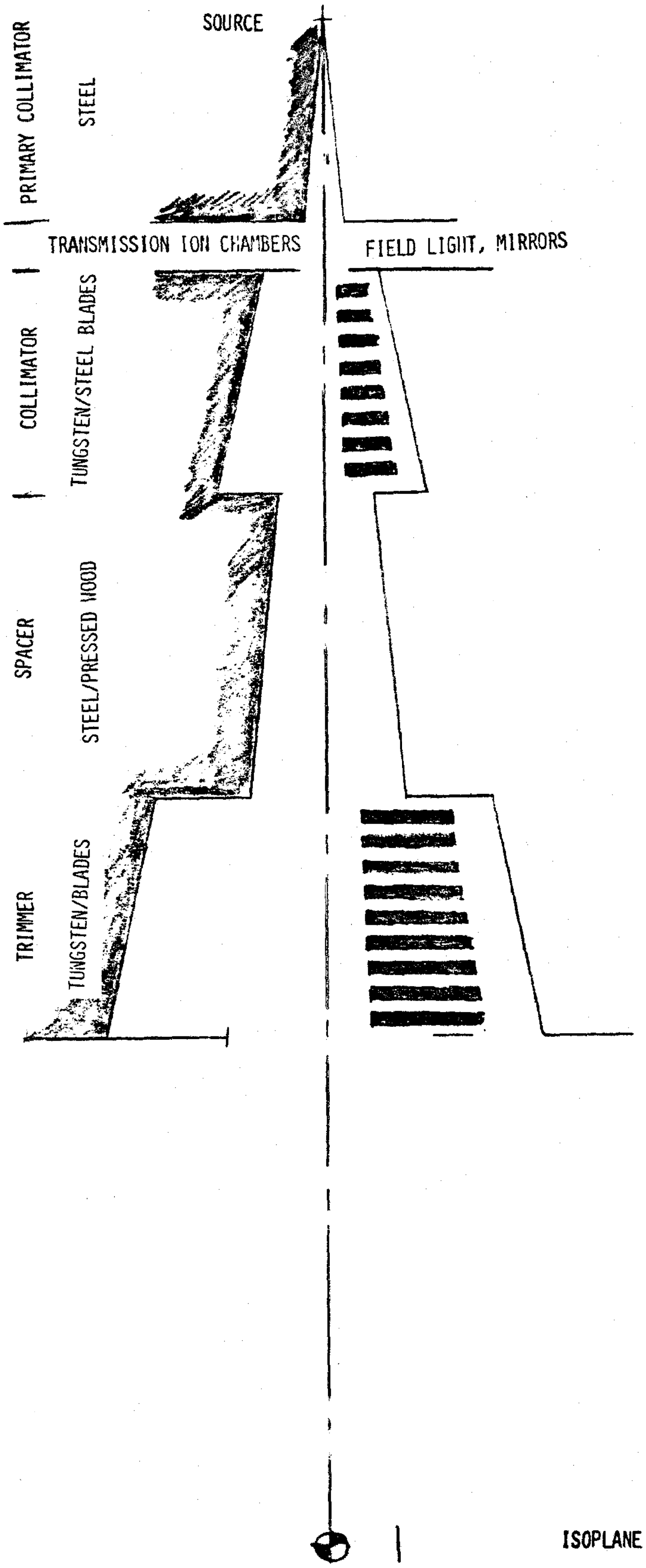
The edge of the individual plates should probably be slanted so that they would follow the dashed line in Figure 2, when the field has a nominal width W_0 of 10 cm.

CONCLUSIONS

Continuously adjustable collimators with attenuation properties suitable for use in fast neutron radiation therapy appear to be feasible with present-day technology. Various possible conceptual designs for such collimators were presented. These collimators would shape neutron beams having penumbras comparable, if not better than, those produced by the hydrogenous collimators now in use at most fast neutron beam therapy centers. In addition, they would solve storage, handling, and personnel exposure problems.

REFERENCES

(1) Miguel Awschalom, Allen F. Hrejsa, Ivan Rosenberg, "Kerma Transmission for Various Materials for a p(66MeV)Be(49MeV) Neutron Beam", Fermilab TM-895, September, 1979.



MODEL					
1	0	19	—	—	77	100 cm
2	0		—	—	54	100 cm
3	0		24	40	70	100 cm
4	0		24	47	77	100 cm
5	0		24	54	84	100 cm

Figure 1

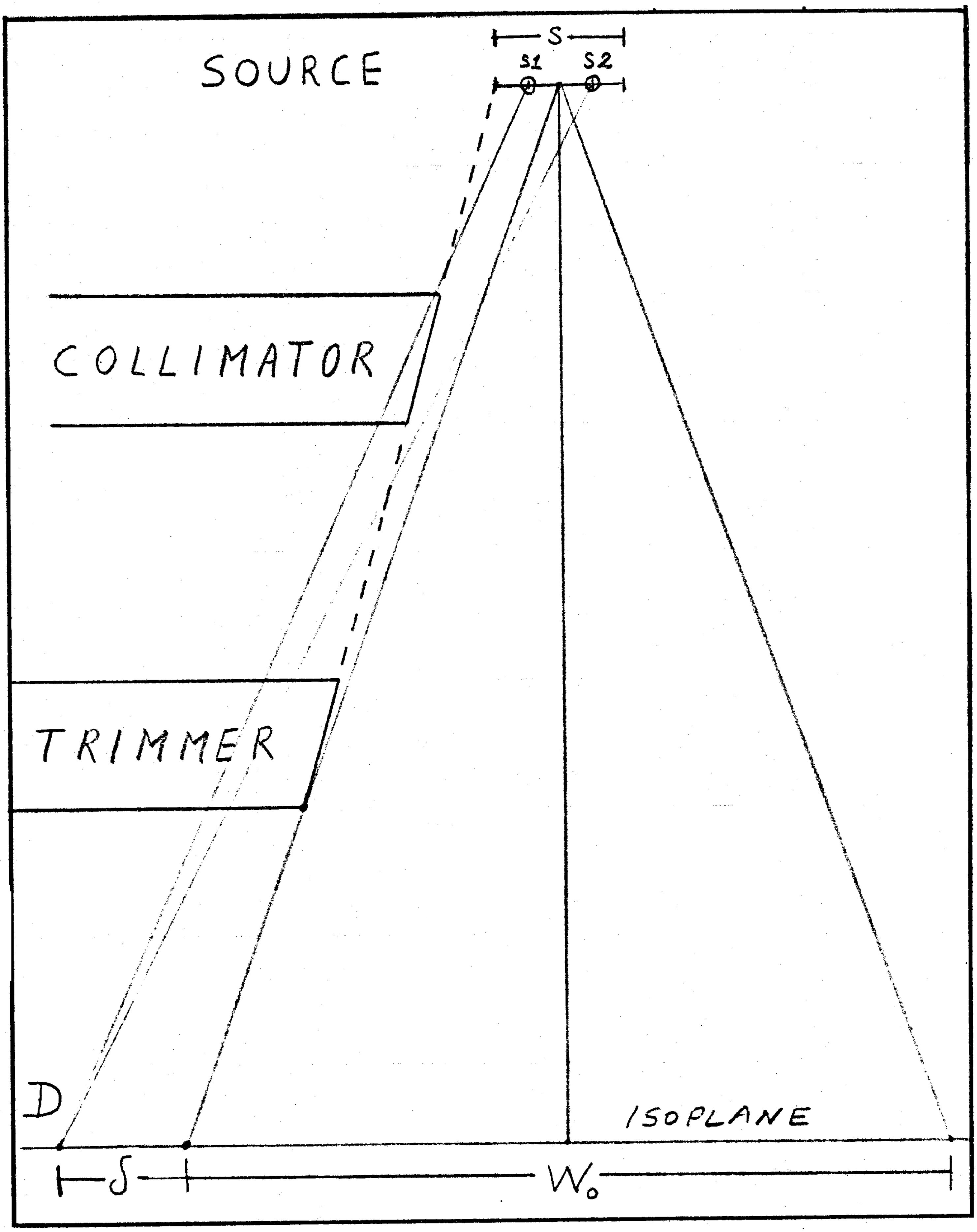
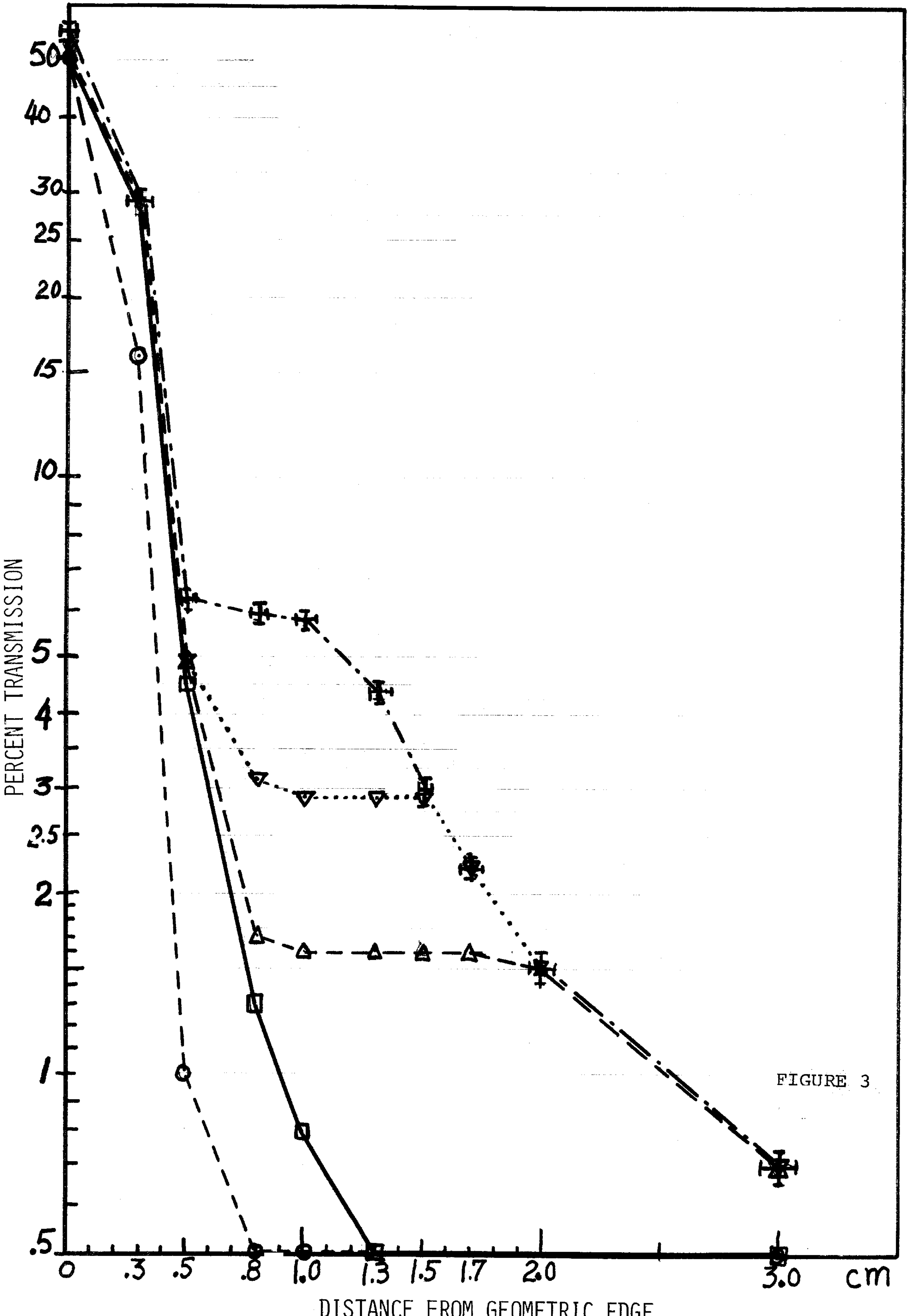


FIGURE 2



50
40
30
25
20
15
10
5
4
3
2.5
2
1
.5
PERCENT TRANSMISSION
0
.3
.5
.8
1.0
1.3
1.5
1.7
2.0
3.0
cm
DISTANCE FROM GEOMETRIC EDGE

FIGURE 3